ELSEVIER

Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia Environmental Sciences 12 (2012) 325 – 332

Procedia Environmental Sciences

2011 International Conference on Environmental Science and Engineering (ICESE 2011)

Method to Predict Proppant flowback in Fractured Gas well

Qi zhilin, Jiao Guoying

Chongqing University of science & technology CQUST Chongqing,China
qizhilin76@sina.com, jiaoguoying520@163.com

Abstract

It has influences on the production of gas well and the effects of fracture when proppant flowback in the fractured gas well and the loss of the proppant from the fracture will corrupt the equipment above and below ground. For the problem of proppant flowback in fractured gas well, the purpose of this paper is to building a model of predict the proppant flowback in fractured gas well.With this model, the necessary control measures can provided to the designers during fracturing design stage, and Provide the basis for the rational allocation of production after the fracture. The prediction model includes both critical rate model of fracture and fracture shunt model. The critical gas rate at which depends on the moment balance of the proppant cracks can find out the critical velocity of gas. Then, Correct the critical velocity based on the formation closure stress, proppant size and strength, natural gas properties and gas seepage law. Last, the critical gas rate of fracture is computed using the gas velocity at borehole wall. Shunt a model of gas distribution between fracture and matrix depends on the numerical simulation. Demonstrate the usefulness of the model because the prediction results of the model agree with production data.

Keywords: Fracturing; Gas well; Proppant flowback; Prediction mothod

1. Introduction

Fractured gas well is more easily to experience proppant flowback than fractured oil well during the production stage because fluid rate is higher in gas well. some gas well occurs proppant flowback phenomenon in the production process after fracturing of XinJiang oilfield and ChangQing oilfield. The middle layer of some wells will buried in sand rapidly, so sand removal is often taken to restore the productivity of wells. These proppant produced can erode downhole and surface equipment. In addition, the fracture become "chocked fracture" if a mass of proppant near wellbore is taken which will affect performance of the fractured well. Against the proppant flowback in fractured gas well, research a method

1878-0296 © 2011 Published by Elsevier B.V. Selection and/or peer-review under responsibility of National University of Singapore. Open access under CC BY-NC-ND license. doi:10.1016/j.proenv.2012.01.285

to predict and build a model for it, which can help to predict the trend of proppant flowback during fracturing design stage and guide the design and construction personnel to use the appropriate control measures.

2. Factors to influence proppant flowback

1).*Fracture width* Fracture width is the most sensitive factor for proppant flowback. In 1992, Milton-Tayer [1] had deeply investigated proppant flowback by a lot of laboratory experiments. He had found that proppant pack became unstable from stable in a small range of fracture width-proppant diameter ratio. Proppant pack is usually unstable when fracture width is bigger than sextuple proppant diameter. Cracks are usually unstable When the Fracture width of 6 times of particle diameter. Even though these conclusions were draw without considering interaction between fracture width and the others factors, but they could give the engineers guidance in the well site.

2).*Fracture closure stress* Fracture closure stress has important effect on proppant flowback. Increasing closure stress will increase frictional force among proppant grains, which make proppant pack stable. Otherwise, too much closure stress could also cause proppant flowback. One of the reasons is possible that a portion of proppant is crushed when closure stress is bigger than nominal strength of the proppant, part of the proppant is crushed, which caused particles filling in the structure of friction-induced instability and proppant flowback.

A little propant is crushed under the relatively low closure stress conditions. As more and more fluid is produced, closure stress will increase and the percent of crush will increase. Then the proppant pack becomes more stable structure again.

3).*Drag force* Drag force is directly related to pressure drop so long as fluid pass through the proppant pack. The pressure drop is directly in proportion to fluid viscosity and fluid velocity, and is inverse proportion to the permeability of the proppant pack. Viscous fluid will produce a larger force of instability. How drag force effect proppant pack depend on fracture closure stress. Pack is unstable either under the condition of ultimate low closure stress or ultimate high closure stress. A finite drag force can make the pack instability. So contras, drag force are key factor for proppant flowback under the condition of medium closure stress. The rates of sand production increase with fluid flow rate as long as proppant flowback begin. Asgin [2] had study the stabilization of propped fracture by the Distinct Element Method. He found that the drag force transported unconsolidated proppant under the low pressure drop gradient and affected the stabilizion of propped fracture under the high pressure drop gradient.

4).*Proppant* the critical speed of proppant with large diameter is higher than the proppant with small diameter, and large proppant filling layer added stability. Uniform distribution of proppant makes pack more stable, but the mixture of different size proppant affect the stabilization of pack. Sintered proppant pack is more stable than melting proppant pack. The above conclusion had confirmed from the experiment of proppant flowback.

3. The predict model of proppant flowback

Since the 1990s overseas has began to study the prediction of proppant flowback, and the prediction method had been proposed can be divided into four categories. The first category is determining the critical velocity of fluid in different closure stress and fracture width on the experimental device of proppant flowback indoor, and drawn into a plate or fitting for the empirical formula[3][4];the second category is introduces a "flow" theory from chemical engineering and mechanical engineering, then calculate the critical velocity of proppant flow back by the flow parameters[5]; the third one is semi-mechanical prediction[4];and the last one is numerical methods[6][7].

Base on achievements of theoretical study and laboratory study, this paper present a prediction model of proppant flowback. The model considers formation properties, proppant properties, Artificial crack size, and the fluid property and gas seepage law of production. The prediction model includes critical rate model of fracture and fracture shunt model.

3.1 Shunt model of fractured gas well

We had made some Hypothesis:

1).The fracture was symmetrical and the fracture height was constant.

2).The fluid was single-phase and it obeyed to non-darcy's law.

3).The reservoir rock was homogeneous and isotropy.

4).We didn't consider the compressibility of the rock and the proppant.

5).The formation temperature kept constant.

6).Ignore the influence of gravity.

7).Formation is a two-dimensional flow, and crack in a one-dimensional flow.

8).Ignore the vertical flow of ground and cracks.

Partial differential equation describing that single-phase compressive fluid unsteadily flow through formation is:

$$\nabla\left[\delta K \nabla \psi\right] = \phi \mu_g C_g \frac{\partial \psi}{\partial t} \qquad (1)$$

Where

$$\delta_x = \frac{1}{1 + \frac{\beta \rho K}{\mu} v_x}$$

$$\delta_y = \frac{1}{1 + \frac{\beta \rho K}{\mu} v_y}$$

$$\psi(P) = 2\int_{P^0}^{P} \frac{P}{\mu_g z} dP$$

Boundary condition

$$\psi\big|_{\Omega} = \psi_{wf} \qquad (2)$$

$$\frac{\partial \psi}{\partial n}\Big|_{\Omega_1} = 0 \qquad (3)$$

Initial condition

$$\psi\big|_{t=0} = \psi_i \qquad (4)$$

Partial differential equation describing that single-phase compressive fluid unsteadily flow through formation is

$$\frac{\partial}{\partial x}\left[\delta K_f \frac{\partial \psi_f}{\partial x}\right] + \frac{K}{W_f}\frac{\partial \psi}{\partial y}\Big|_{y=0} = \phi_f \mu_g C_g \frac{\partial \psi_f}{\partial t} \tag{5}$$

Boundary condition

$$\psi_f\big|_{x=0} = \psi_{wf} \tag{6}$$

Initial condition

$$\psi_f\big|_{t=0} = \psi_i \tag{7}$$

Because the formation and fracture are symmetrical with wellbore, one fourth formation is taken as study unit when solving the numerical problem. We gridded the formation and the fracture, implicitly differenced the fracture flow equation (5) and the formation flow equation (1) and solved the system of equations with alternating iteration method. We matched Simulating results as empirical correlation (R^2=0.9208). Have the following model of fluids in the formation and distribution of crack between the mathematical:

$$Q_f \Big/ Q_t = 4.9731 Ln\left[\frac{(K_f - K)w}{K}\right] + 78.157 \tag{8}$$

By eq. 8 we know, indicates that the percentage of flux from fracture has nothing to do with the output fluid property, and it has nothing to do with fracture length while doing sensitivity analysis.

Without considering non-darcy of gas, the empirical correlation is

$$Q_f \Big/ Q_t = 5.2388 Ln\left[\frac{(K_f - K)w}{K}\right] + 78.665 \tag{9}$$

3.2 Critical rate model of fracture gas well

There are two kinds of transportation how proppant is transported from the fracture into wellbore. One is that proppant is taken into wellbore while being suspended in formation fluids, even though take out the ground; the other is that proppant roll to wellbore by the fluid impacting force, or carried to the ground by the speed of fluid . This paper considered the last one.

Before developing the critical rate model, we had made some hypothesis:

1).Proppant in manual fracture was round (fig.1) and proppant diameter kept constant.

2).Fracture height was marked as h_f and fracture width was signed as w_f.

3).Fluid impacting force and effective gravity of proppant were considered while developing the model. The other forces were neglected.

4).Fluid temperature kept constant while flowing through the fracture.

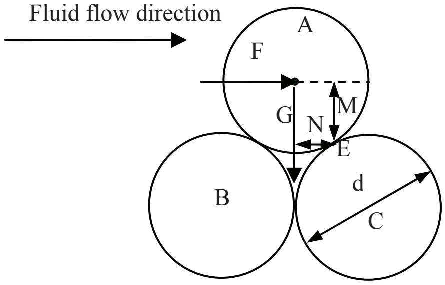

Fig.1. force analytical graph of prppant in fracture

We firstly developed the critical velocity model without considering closure stress, fracture width and proppant strength.Then we corrected the model.

As the fig.1 show, in the effect of the fluid impact and the action of gravity, A proppant scroll with the E point as a fulcrum. Base on moment balance principle, the critical fluid velocity causing proppant to product could be calculated by following equation.

$$v_{cf} = \frac{1}{3}\sqrt{2\sqrt{3}\,\frac{gd(\rho_p - \rho_f)}{\rho_f}} \qquad (10)$$

In fact, fracture width is very small,and formation closure stress acting on proppant pack. So we must correct the model.

If natural gas flows according to Darcy's law, the actual critcal velocity could be calculated.

$$v_{ca} = v_{cf} + \beta \qquad (11)$$

Where

$$\beta = 2.2396\times10^{-5}\frac{W_T K_f}{\mu_g}\exp\left[-0.5\left(\frac{\ln P_c - \alpha'}{S_T}\right)^2\right]$$

$$W_T = 1422.5\exp(-1.0483W_r)$$

$$S_T = 4.35\times10^{-3}S_{\max} + 0.22368$$

If gas flow in fracture according to non-darcy's law, then gas flow described by Forchheimer's equation. Base on that the total pressure drop is pressure drop caused by critical velocity plus additional pressure drop caused by closure stress, the actual critical velocity could be expressed as

$$v_{ca} = \frac{-B + \sqrt{B^2 - 4AC}}{2A} \qquad (12)$$

Where

$$C = -0.02262 W_T \exp\left[-0.5\left(\frac{\ln(p_{c,net}) - \alpha'}{S_T}\right)^2\right] - Av_{cf}^2 - Bv_{cf}$$

$$A = 1013\beta\rho_g \quad B = 1013\mu_g / K_f \quad \beta = b / K_f^a$$

We calculated the critical flow rate of fracture base on the critical velocity in the entrance of fracture. The critical flow rate was

$$Q_{cg} = 17.28 h_f w_f \phi_p v_{ca} \frac{T_{SC}}{zT} \frac{p}{p_{sc}} \quad (13)$$

The critical gas production rate can be derived by substituting eq. 13 to eq. 9 with non-darcy' effect. The critical gas production rate can be derived by substituting eq. 13 to eq. 8 without non-darcy' effect.

4. Application

Fundamental parameters of case well are listed in table 1. The critical gas production rate calculated using developed method is $4.64\times10^4 m^3/d$. The result agrees well with that of literature [8]. Proppant flowback happened when the production rate was bigger than $7.0\times10^4 m^3/d$, but it didn't happen if the production rate was smaller than $4.1\times10^4 m^3/d$. The facts validate the prediction result. The actual production rate was $7.0\times10^4 m^3/d$ when proppant flowback happened. The drag force caused by high production rate mainly contributed to proppant flowback and small closure stresss also contributed to it.

Table 1 Input data of model

Formation permeability(um^2)	6.50E-04	Fracture width(m)	3.02E-03
Formation pressure(MPa)	27.41	Fracture height(m)	23.4
Closure stress(MPa)	39	Proppant density(kg/m^3)	1730
Gas density(kg/m^3)	156.79	Mean diameter(m)	6.00E-04
Gas viscosity(mPa.s)	0.02	Propant permeability(um^2)	60
Gas deviation factor	0.94	Propant porosity	0.105
Formation temperature(℃)	92	Proppant nominal strength(MPa)	80

5. Result

1). This paper present a model to predict proppant flowback in fractured gas well. The model consideres formation closure stress, formation fluid property, gas flow characteristic, proppant and fracture geometry. The predictive result agreed well with that of production data.

2). The percentage of flux from the fracture to total production rate have nothing to do with produced fluid property and it has nothing to do with fracture length when fracture length is small.

3). Formation closure stress and fluid drag force play an important roll in proppant flowback of fractured gas well.

4). Non-darcy's effect almostly have no effect on the percentage of flux from the fracture to total production rate, so it can be neglected in practice.

5). Proppant flowback mechanism is the base of Proppant flowback prediction. More attention will be paid to the mechanism of proppant flowback and laboratory equipments should be improved to help to understand proppant flowback as soon as possible.

6. Acknowledgment

This research is funded by Chongqing Natural Science Foundation. The project No. is CSTC,2010BB4281.

Nomenclature

t=time, s
δ=correction coefficient of non-darcy flow
v=gas flow velocity through porous medium, m/s
Ψ=pseudo pressure function
K=formation permeability, m^2
P=pressure,Pa
z=deviation factor, decimal fraction
φ=formation porosity,decimal fraction
μ_g=gas viscosity, mPa·s
C_g=natural gas compressibility factor, 1/Pa
Ω_1= outer boundary
Ω= inner boundary
n=boundary normal direction
K_f=fracture permeability, m^2
φ=formation porosity,decimal fraction
Q_f=flux from the fracture, m^3/s
Q_t=production rate, m^3/s
w=fracture width, m
v_{ca}, v_{cf}=fluid critical velocity, m/s
d=proppant mean diameter
W_r=farcture weidh-proppant mean diameter ratio
P_c=effective closure stess, MPa
S_{max}=proppant nominal strength, MPa
Q_{sg}=gas critical flow rate, $10^4 m^3/d$
T=formation temperature, K
p=mean formation pressure, MPa
SC=standard conditions

References

[1]Milton-Tayler D., Stephenson C. and Asgian M.I. Factors Affecting the Stability of Proppant in Propped Fractures: Results of a Laboratory Study[C]. SPE 24821, 1992

[2]Asgin M.I., Cundall P.A. and Grady B.H. The Mechanical Stability of Propped Hydraulic Fractures: A Numerical Study[C]. SPE 28510, 1994

[3]Andrews J.S. and Kjorholt H. Roch mechanical principles help to predict proppant flowback from hydraulic fracture[C]. SPE 47392, 1998

[4]Canon J.M., Romero D.J., and Pham T.T. etc. Avoiding Proppant Flowback in Tight-Gas Completions With Improved Fracture Design[C]. SPE 84310, 2003

[5]Sparlin D.D. and Hagen R.W. Proppant Selection for Fracturing and Sand Control[J]. World Oil, January 1995:37-40

[6]Parker M., Weaver J. and Batenburg D.V. Understanding Proppant Flowback[C]. SPE 56726,1999

[7]Batenburg D.V., Bjizen E. and Weaver J. Towards Proppant Back-Production Prediction[C]. SPE 54730, 1999

[8]Junzheng Song. Fracture fluid flowback model and reasonable productivity of fractured gas well without proppant flowback. Sichuan chengdu: Southwest Petroleum University, 2005.